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Performance Testing Prototype Nozzles and Receptacles for the Standard Army Refueling System

by

William D. Perdue

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Belvoir RD&E Center

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Section I
Introduction

Existing refueling hardware and on-board equipment fuel systems do not allow for rapid refueling of combat vehicles or combat support equipment. Current refueling methods and equipment limit flow rates, require multiple tank refueling from more than one location, and do not provide for the return of vapors to the fuel source. The Standard Army Refueling System (SARS) program strives to alleviate as many of these problems as technically feasible. Army Materiel Command Regulation, AMCR 70-17, "Implementation of the Standard Army Refueling System," establishes criteria for designing combat vehicles and ground support equipment fuel systems. Published in 1989, the regulation requires total refueling in a maximum of two minutes. Based on this rapid refueling mandate, the regulation identifies the need to develop a nozzle and receiving system that provides fuel at high flow rates to all combat-related hardware.

The process of identifying a nozzle and receptacle began with a market investigation and the purchase of four different prototypes for testing. The prototype testing provided an opportunity to validate the SARS technical requirements and performance parameters. Information gained will provide the basis for the development of the next generation prototype SARS nozzle and receptacle.

Originally, each SARS prototype was to undergo a full complement of performance, reliability, and environmental tests; but, due to problems experienced during nozzle development, some units could not satisfy all requirements of the SARS Purchase Description (see Appendix). Consequently, each prototype's test procedure was tailored to its particular capabilities.

This report provides the results of performance testing of the initial prototypes, designed and manufactured to satisfy the SARS requirements.

Section II
Test Procedures

We developed a test plan to evaluate the performance of each prototype nozzle and receptacle (report number VSE/ASD/0163-90/39RD, "Test Plan for the Evaluation of the SARS Nozzle and Receptacle"). The tests were to evaluate flow and pressure regulation, automatic shut-off, and operation after exposure to various climatic extremes. Each procedure in the original test plan was designed to evaluate a specific performance requirement contained in the SARS purchase description. Based on information and recommendations from each manufacturer, we modified the test procedures to account for the deficiencies of each prototype. After preliminary testing, all environmental tests were eliminated and we made other modifications to accommodate test stand limitations. The pump used for testing did not have the capacity required to produce the flow and inlet pressure necessary to perform all of the tests.

Before official testing, each prototype was installed into the test stand for a pretest checkout. The pretest was designed to locate any leaks or incorrect installations.

Section III

Test Facilities

The testing was done at the U.S. Army Belvoir Research, Development, and Engineering Center (BRDEC), Petroleum Test Area, Fort Belvoir, VA. A schematic of the test stand is shown in Figure 1.

We monitored nozzle performance using flowmeters, pressure transducers and thermocouples. The output from each device was automatically read and recorded, once every second, using a Hewlett Packard System 10 data acquisition system and Compaq Model 40 portable computer. Values were recorded for flow rate, internal tank pressure, vapor line pressure, supply line pressure, fuel temperature, and ambient temperature. Test fluid was JP-5 fuel conforming to MIL-T-5624, Turbine Fuel, Aviation, Grades JP-4 and JP-5.

The test pumping unit, consisting of a diesel-engine-driven end suction centrifugal pump, was rated at 200 gallons per minute (gpm) - 175 feet total head at a speed of 3,550 rpm.

DEVICES

A listing of the devices used to complete this testing is given below:

- Data Acquisition System
  - Hewlett Packard, HP75000 Series B, Model E1300A
- Computer
  - Compaq SLT/286, Model 40, 80C286 microprocessor
- Power Supply
  - Hewlett Packard, Model 6236B
- Pressure Transducers
  - Omega, Model PX105 - 0 to 6 psig
  - Omega, Model PX105 - 0 to 200 psig
- Pumping Assembly
  - Pump - Peabody Barnes, Model US33HACD, 200 gpm at 175 feet total head
  - Engine - Ruggerini model MD151, 13 hp at 3,600 rpm
- Flow Meters
  - Hoffer Flow Controls, Model HO1x1-8-130-B-IMC3PAX-FICS
  - Hoffer Flow Controls, Model HO4X4-75-1250-B-1MX-VIC-H20

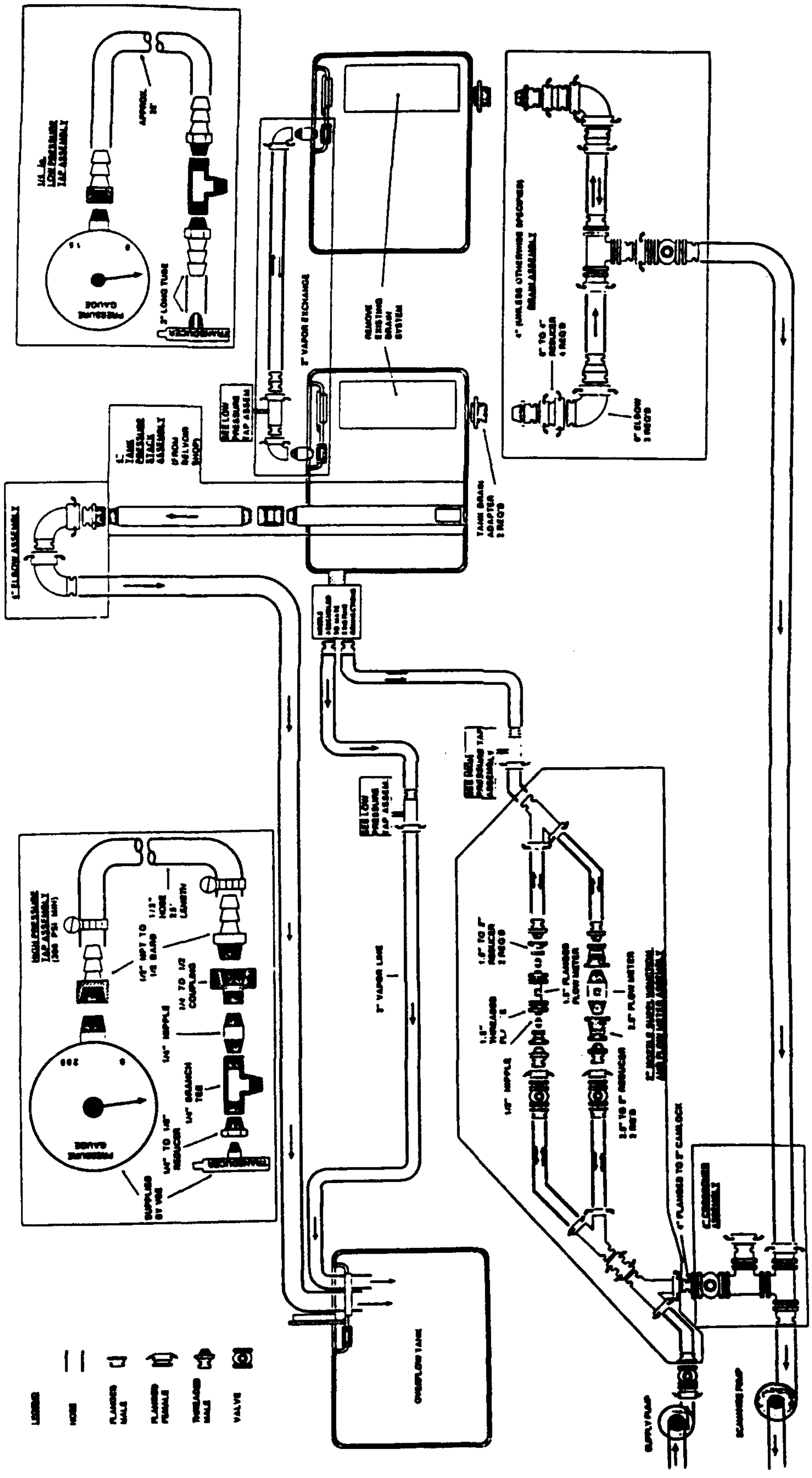

Figure 1. Schematic of SARS Test Sand

HARDWARE

Table 1 provides a list of the evaluated prototype nozzles and receptacles. Each prototype was subjected to limited testing by its respective manufacturer before delivery to the Government.

Table 1. Listing of Test Hardware

ITEM	MANUFACTURER	PART NUMBER
Nozzle	Aeroquip	AE87199Z
Receptacle	Aeroquip	AE87200Z
Nozzle	Moog Inc.	50X632
Receptacle	Moog Inc.	———
Nozzle	Tube Alloy	300-0000
Receptacle	Tube Alloy	300-7000
Nozzle	Wiggins	SK894/001
Receptacle	Wiggins	———
Nozzle	Wiggins	SK894/002
Receptacle	Wiggins	———

Section IV
Test Results

AEROQUIP NOZZLE AND RECEPTACLE

The Aeroquip nozzle is equipped with a pressure regulating device that supplies a constant pressure to the mating equipment receptacle. The receptacle contains a properly sized orifice that allows complete filling of the tank(s) within two minutes. The receptacle also includes a vapor vent valve that provides the passageway for the return of fuel vapors through the receptacle and nozzle back to the supply tank. A cross section of the nozzle and receptacle is given in Figure 2. The nozzle attaches to the receptacle through a three lug bayonet type connection. To initiate flow, the handle located on the side of the nozzle is rotated to the "ON" position. As the fuel level rises, the ball float type vent valve is forced shut. This allows internal tank pressure to increase, signaling the nozzle that the tank is full. The nozzle automatically closes, terminating flow. The flow handle is manually returned to the "OFF" position and the nozzle is disconnected from the receptacle by rotating the bayonet ring.

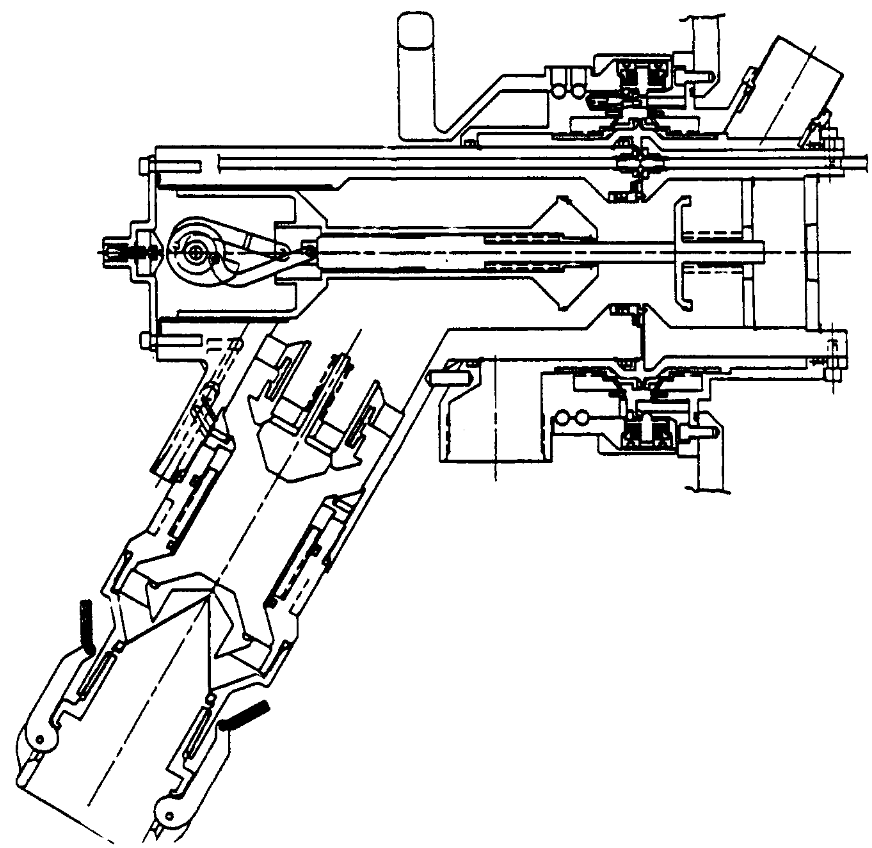

Figure 2. Cross Section of the Aeroquip Nozzle and Receptacle

Five orifice plates were provided with the prototype nozzle and receptacle. Table 2 lists the orifice diameters and expected flow ranges.

Table 2. Orifice Sizes and Expected Flow Rates for Aeroquip Nozzle and Receptacle

		FLOW (gpm)				
		PRESSURE (psi)				
PART NO.	DIAMETER (inches)	25	50	75	100	125
DE8021-73-24-1	.500	21.5	22.5	22.7	19.8	21.2
DE8021-73-24-2	1.040	81.0	85.0	84.3	86.1	89.6
DE8021-73-24-3	1.250	121.7	130.5	127.6	134.4	136.4
DE8021-73-24-4	1.500	165.7	169.5	181.5	199.7	——
DE8021-73-24-5	1.750	175.8	199.7	231.0	274.6	——

The hardware provided to the Government, nozzle AE87199Z and receptacle AE87200Z, did not satisfy all of the SARS Purchase Description requirements. Specifically:

- Weight - The weight of the prototype nozzle is 20.7 pounds. A cast version is estimated to weigh approximately 14 to 15 pounds, which exceeds the 12 pound limit required by the SARS purchase description.
- Emergency disconnect - No provisions for emergency disconnect between the nozzle and receptacle are incorporated into the design. This feature allows the item receiving fuel to drive away while the nozzle automatically disengages from the receptacle. The disengagement causes no damage to the vehicle receptacle or nozzle while limiting the spillage of fuel. Aeroquip did incorporate a partial design for the emergency breakaway feature that was tested with a dry nozzle. After breakaway, the nozzle and receptacle exhibited signs of abnormal wear. The design does not incorporate any method of shutting off fuel flow after breakaway.
- Dust caps - No dust caps are provided for either the discharge side of the nozzle or the inlet of the receptacle. This deficiency did not affect performance testing.
- Corrosion protection - The outer surfaces of the prototype are not protected against corrosion by painting or anodizing.

Pretest Inspection

Prior to testing, we examined the nozzle and receptacle for missing or damaged parts, defects and damaged seals. All parts were in proper working condition except for the small pins located in the end of the nozzle. As shown in Figure 3, these pins were bent approximately 30 to 45 degrees. We straightened the pins and then connected the nozzle to the receptacle. The nozzle appeared to lock into place as required. It is not known how the pins became bent. A visual shutoff indicator was located on the rear of the nozzle and a strainer was found in the nozzle inlet.

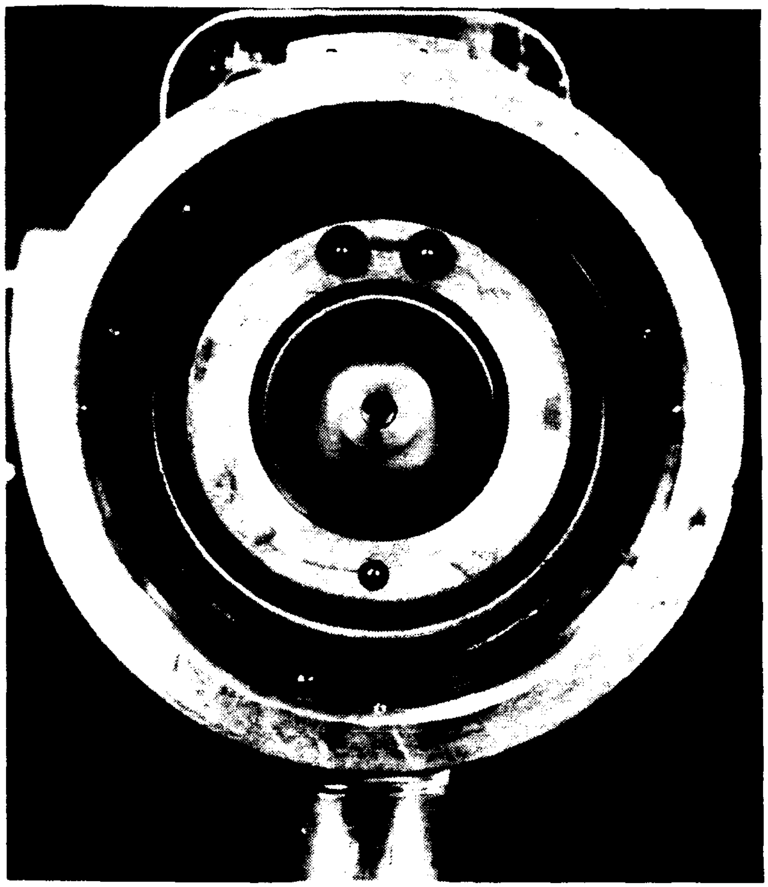

Figure 3. End View of Aeroquip Nozzle Showing Broken and Bent Pins

Connect/Disconnect

With the fuel and vapor recovery hoses attached, the nozzle was connected to and disconnected from the receptacle 15 times. The time required for each connection was measured and recorded. First, the operator completed several cycles to become familiar with the sequence required to properly engage the nozzle. After several practice cycles, the 15 cycle test was conducted. It took an average of 4 seconds to complete the connection process. The relative position of the receptacle and nozzle affects the connection time. For the purpose of this test, the receptacle was about 3 feet from the ground, allowing the connection to be made at belt level. Receptacle locations above the operator's shoulder level will be significantly more difficult to connect. After completion of the 15 cycles, small metal shavings were observed on the face of the nozzle and the receptacle. The size and quantity of the shavings indicated excessive wear for the number of completed connections.

On/Off Flow Cycle Test Using Orifice Plate DE8021-73-24-1

We conducted flow cycle (30 second flow/no flow intervals) testing with orifice plate DE8021-73-24-1 installed in the receptacle. Flow rates averaged 19 gpm at an inlet pressure of 23 psig over the 15 cycle test. Table 3 gives a sample of the data taken. Data remained consistent throughout the cycle testing, indicating no operational problems. During the no flow portion, we recorded static pressures of 27 to 28 psi, with no indication of leakage or other malfunction. The nozzle remained in the "OFF" position for the duration of each 30 second cycle. We encountered problems determining the position of the flow handle. There appeared to be no predetermined location that the handle had to assume for operation, making it difficult to determine when flow started. In addition, the handle was very difficult to operate (see Figure 4). It required two hands to change the position of the handle from "ON" to "OFF" and vice versa.

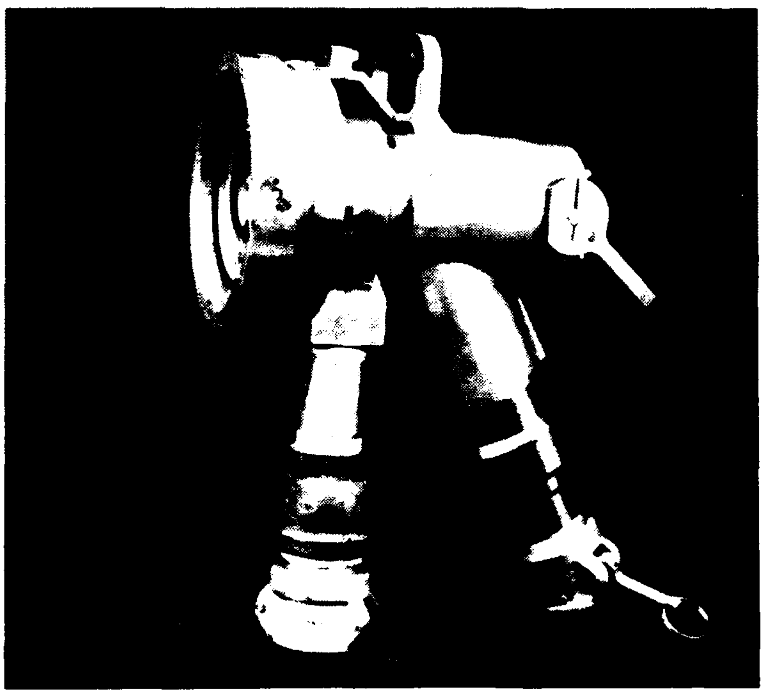

Figure 4. Picture of Aeroquip Nozzle Showing the Small Flow Handle that Required Rotation to Initiate Flow

Table 3. Sample Flow Rates and Pressures of Aeroquip Nozzle Using Orifice Number DE8021-73-24-1

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
140	-0.1219	-0.0731	23.125	18.8906	57.7607	54.3875
141	-0.1219	-0.0638	22.8125	18.9414	57.824	54.3664
142	-0.1313	-0.0591	22.9688	18.6875	57.7748	54.3312
143	-0.1313	-0.0684	22.6562	19.0403	57.7432	54.3137
144	-0.1313	-0.0591	22.3438	18.8906	57.7889	54.3014
145	-0.1266	-0.0638	22.9688	18.7383	57.8152	54.3506
146	-0.1172	-0.0731	22.9688	18.6875	57.7994	54.34
147	-0.1172	-0.0638	23.125	18.7891	57.7168	54.4543
148	-0.1219	-0.0825	22.0312	18.9414	57.7484	54.5387
149	-0.1453	-0.0731	23.125	18.7383	57.7695	54.6178
150	-0.1078	-0.0731	22.6562	18.8398	57.8047	54.674
151	-0.1172	-0.0591	23.125	18.7383	57.8135	54.834
152	-0.1219	-0.0919	22.5	19.043	57.7766	54.8586
153	-0.1125	-0.0544	22.8125	18.7891	57.8996	54.892
154	-0.1313	-0.0591	22.9688	18.8398	57.7871	54.95
155	-0.1266	-0.0731	22.6562	19.0938	57.8768	54.9922
156	-0.1172	-0.0591	22.8125	18.7891	57.8381	54.9535
157	-0.1078	-0.0684	22.9688	18.8906	57.8205	54.9746
158	-0.1406	-0.0825	22.1875	18.9414	57.8803	54.9746
159	-0.1266	-0.0778	22.6562	19.043	57.875	54.834
160	-0.1172	-0.0684	22.5	18.8906	57.8732	54.8428
161	-0.1219	-0.0731	22.9688	19.1445	57.8064	54.8639
162	-0.1219	-0.0778	22.3438	18.8906	57.817	54.7936
163	-0.1219	-0.0778	23.5938	18.9922	57.7695	54.7619
164	-0.1406	-0.0638	23.75	16.1992	57.8416	54.6951
165	-0.1359	-0.0778	27.9688	4.3672	57.8135	54.6266
166	-0.1359	-0.0684	27.6562	0.7109	57.7221	54.6688
167	-0.1313	-0.0731	27.5	0.1523	57.7555	54.6564
168	-0.1219	-0.0684	27.6562	0.1523	57.7273	54.5211
169	-0.1125	-0.0731	27.3438	0.1523	57.8047	54.5738
170	-0.1266	-0.0825	27.5	0.2031	57.7625	54.493
171	-0.1313	-0.0684	27.3438	0.1523	57.7291	54.4543
172	-0.1313	-0.0684	26.875	0.3047	57.7766	54.6037
173	-0.1313	-0.0731	27.0312	0	57.8029	54.5387

Automatic Shutoff Test

After completion of the ON/OFF cycle testing, flow was allowed to continue until the nozzle/receptacle automatically shut off. Table 4 provides the data for the final 30 seconds before flow termination. During the last 5 seconds, flow went from 18.1 to 14.1 and finally to 3.2 gpm before full shutoff by the nozzle.

Table 4. Flow Rate and Pressure Values Recorded During Final 30 Seconds of Automatic Shutoff Test of Aeroquip Nozzle Using Orifice Number DE8021-73-24-1

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
140	1.2469	-0.0731	25.3125	19.7539	58.165	53.9094
141	1.2797	-0.0684	25.4688	19.6523	58.1053	53.9428
142	1.3078	-0.0731	24.8438	19.5	58.1545	53.9375
143	1.3594	-0.0825	24.8438	19.6016	58.1686	53.9428
144	1.3828	-0.0638	25.625	19.5	58.158	53.9375
145	1.4156	-0.0731	24.8438	19.1445	58.1475	53.876
146	1.4672	-0.0497	25.3125	19.2969	58.1949	53.9305
147	1.4906	-0.0684	25	19.4492	58.1211	53.8971
148	1.5094	-0.0497	25.3125	19.1953	58.1527	53.9129
149	1.5563	-0.0778	25	19.0938	58.1123	53.9129
150	1.5797	-0.0684	25.1562	19.2461	58.1352	53.9199
151	1.6313	-0.0731	24.6875	18.9414	58.2143	53.9568
152	1.6547	-0.0778	24.2188	18.8906	58.1246	53.9393
153	1.6781	-0.0684	24.2188	18.7891	58.1176	53.8953
154	1.7344	-0.0731	24.2188	18.6875	58.1352	53.9516
155	1.7438	-0.0684	23.5938	18.7383	58.1984	53.8619
156	1.7859	-0.0778	24.375	18.7383	58.1457	53.9217
157	1.8375	-0.0731	24.0625	18.5859	58.1562	53.8672
158	1.8703	-0.0731	24.6875	18.4336	58.1721	53.9832
159	1.8984	-0.0731	24.2188	18.6367	58.2248	53.9287
160	1.9266	-0.0825	23.75	18.332	58.1668	53.927
161	1.9641	-0.0684	23.4375	18.5352	58.1967	53.9533
162	2.0016	-0.0591	23.9062	18.1289	58.1809	53.9111
163	2.0203	-0.0684	23.75	18.4844	58.202	53.9498
164	2.0672	-0.0778	23.4375	18.3828	58.3039	53.934
165	2.0859	-0.0591	22.9688	18.332	58.2283	53.9604
166	2.1141	-0.0872	23.5938	18.0781	58.2072	53.992
167	2.1375	-0.0731	22.9688	15.4883	58.1756	54.0025
168	2.1703	-0.0638	28.125	14.1172	58.165	53.9533
169	2.1516	-0.0591	27.5	3.1992	58.1176	54.0975
170	2.1609	-0.0825	27.9688	0.4063	58.1176	53.9146

This closure process started at an internal tank pressure of about 2.1 and reached a high near 2.17 psig, which was above the 1.5 psig limit specified in the SARS Purchase Description. The vapor recovery line was free of fuel after shutoff.

On/Off Flow Cycle Test Using Orifice Plate DE8021-73-24-2

We changed the orifice plate in the receptacle to plate number DE8021-73-24-2 and repeated the 30 second ON/OFF cycle and automatic shutoff tests. Data recorded during the cycle test, Table 5, indicated that the nozzle did not completely close when the nozzle was manually shut off. Between 4 and 5 gpm continued to pass through the nozzle. A check on the nozzle handle showed it to be in the "OFF" position. This anomaly did not occur every cycle. There was no visual indication of the cause of the problem.

After the final ON/OFF cycle, we returned the nozzle handle to the "ON" position, allowing the tank to fill until the nozzle automatically terminated flow. As shown in Table 6, the fuel cell was filled at a flow rate of around 88 gpm with internal tank pressure reaching a maximum of 1.63 psig. We repeated the automatic shutoff test two more times with comparable results.

Operational Problems

Throughout testing, the nozzle developed several operational problems. These included premature flow termination, failure to initiate flow when the flow handle was moved to the "ON" position, and significant leaks at several points. Frequently, the nozzle would terminate flow when the tank level and the internal tank pressure were below shutoff limits. Visual inspection of the nozzle and receptacle did not indicate any reason for the shutdown. Attempts to initiate flow by rotating the flow handle to the "OFF" position and then back to "ON" resulted in flow for a short duration. The flow indicator pin popped out and, within a couple of seconds, flow terminated. The only way to achieve continuous flow was to manually hold the indicator pin in the flow position. Once flow started and stabilized, the nozzle operated for a longer duration before shutting off. This condition continually degraded until the pin had to be manually held in at all times to achieve flow. Additionally, leaks developed around the indicator pin and the nozzle/receptacle interface. The interface leak allowed fuel to enter the vapor recovery line. We terminated further testing of the Aeroquip nozzle due to these operational failures.

Table 5. Flow Rates and Pressures of Aeroquip Nozzle During ON/OFF Cycle Test That Shows Pass-By Flow When Nozzle is in the "OFF" Position

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
320	-0.0375	-0.1106	26.5625	4.3672	50.9826	49.7117
321	-0.0469	-0.0778	25.9375	4.6719	50.9756	49.7117
322	-0.0328	-0.0731	26.0938	4.6719	50.958	49.8418
323	-0.0422	-0.0825	26.25	4.7227	51.0283	49.9068
324	-0.0281	-0.0684	26.0938	4.5703	51.0881	49.9367
325	-0.0281	-0.0731	25.4688	4.4688	51.0037	50.0018
326	-0.0516	-0.0731	25.7812	4.7734	51.0863	50.123
327	-0.0188	-0.0919	28.125	3.3008	51.0354	50.2092
328	-0.0563	-0.0684	33.5938	1.1172	51.0283	50.2197
329	-0.0516	-0.0731	37.5	0.9141	51.1039	50.3498
330	-0.0563	-0.0684	39.5312	2.9453	51.1145	50.4131
331	-0.0375	-0.0591	40	3.4023	51.0775	50.3041
332	0	-0.1013	37.8125	39.7617	51.1057	50.5027
333	0.0844	-0.0403	36.25	65.4063	51.0881	50.6996
334	0.0891	-0.1106	36.0938	70.1797	51.2111	50.8982
335	0.1125	-0.0966	33.4375	71.043	51.1672	51.1725
336	0.1547	-0.0872	35.625	71.8047	51.1883	51.3271
337	0.1547	-0.0403	34.5312	72.2109	51.1303	51.4889
338	0.1359	-0.0497	33.75	71.8555	51.2006	51.7033
339	0.1172	-0.0591	33.125	71.6524	51.2445	51.5855
340	0.1219	-0.0684	32.5	71.1445	51.1443	51.1461
341	0.1172	-0.1153	32.6562	70.6367	51.1777	50.784
342	0.1359	-0.0544	31.875	69.875	51.2076	50.4922
343	0.1406	-0.0825	30.3125	69.5195	51.1531	50.0633
344	0.1313	-0.0638	30.7812	69.2149	51.2287	49.877
345	0.2016	-0.0778	29.2188	69.3164	51.2164	49.6607
346	0.2906	-0.0638	29.2188	68.8086	51.1777	49.448
347	0.4172	-0.0966	29.5312	68.4024	51.2146	49.2494
348	0.5438	-0.0684	28.75	67.9961	51.2129	49.1949
349	0.6469	-0.0684	28.5938	67.6406	51.2199	49.035

Table 6. Flow Rate and Pressure Values Recorded During the Final 30 Seconds Before Automatic Shutoff of the Aeroquip Nozzle Using Orifice DE8021-73-24-2

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
522	0.1547	0.1566	36.4062	89.4258	53.0393	48.3459
523	0.1266	0.1425	36.5625	89.1719	52.9953	48.3811
524	0.1172	0.1284	36.0938	89.4258	53.0164	48.4197
525	0.1359	0.0816	36.0938	89.1211	53.1377	48.4865
526	0.1359	0.1425	36.25	89.375	53.1254	48.3688
527	0.1406	0.2456	36.4062	89.2226	53.1025	48.4232
528	0.1453	0.1472	36.4062	89.2734	53.0586	48.425
529	0.1547	0.1987	36.25	88.9687	53.0516	48.4355
530	0.2156	0.1144	36.25	89.0703	53.041	48.3688
531	0.3	0.1237	35.7812	89.0703	53.1025	48.4004
532	0.3844	0.1331	36.25	88.7656	53.041	48.4109
533	0.4734	0.105	36.7188	88.918	53.0533	48.4162
534	0.5531	0.1144	36.5625	88.7656	53.1236	48.4391
535	0.6516	0.1237	36.25	88.7656	53.0885	48.3652
536	0.7125	0.1284	36.4062	88.6641	52.9531	48.4988
537	0.7875	0.1284	36.5625	88.3594	53.0182	48.4988
538	0.9094	0.1378	37.1875	88.4609	52.9355	48.4602
539	0.9797	0.1144	36.5625	88.207	52.9848	48.4918
540	1.0594	0.1237	36.7188	88.0039	52.8758	48.4373
541	1.1438	0.1284	37.3438	87.9024	52.9795	48.4285
542	1.2328	0.1425	36.25	87.9024	52.8969	48.476
543	1.3125	0.1425	36.7188	88.0039	52.8969	48.3793
544	1.3781	0.1237	36.0938	87.4961	52.9426	48.4338
545	1.4625	0.1378	36.25	87.6992	53.0252	48.5639
546	1.5563	0.1472	36.7188	87.6992	53.0568	48.599
547	1.6219	0.1097	38.75	83.2305	52.9689	48.4004
548	1.6359	0.1378	67.8125	25.7461	52.9918	48.4777
549	1.6313	0.1284	66.25	2.0313	52.8986	48.5551
550	1.6172	0.1144	65.9375	0.2539	52.9584	48.5252
551	1.6078	0.1378	64.6875	0.0508	52.9566	48.5252

Human Factors Engineering Evaluation

We performed a human factors engineering evaluation to ensure conformance to the criteria of MIL-STD-1472, "Human Engineering Design Criteria for Military Systems, Equipment and Facilities." The nozzle is equipped with a pop-out shutoff indicator pin. This type of device does not provide a clear indication of flow as required by MIL-STD-1472, paragraph 5.2.1. Moreover, the size of the indicator makes tactile flow determination difficult. The nozzle is relatively easy to connect and disconnect. However, it is not Arctic mitten compatible, because of the small flow handle.

MOOG, INC. NOZZLE AND RECEPTACLE 50X6323

The Moog design approach deviates from the other prototypes by using two independent, side-by-side passageways for the fluid flow and vapor return lines. A cross section of the Moog nozzle is shown in Figure 5. Both the supply and the vapor return passageways of the Moog nozzle incorporate an enlarged version of an existing rotating ball coupling. The design was successfully used in several aerospace applications. In addition to the increase in size, pressure sensing and regulating features were incorporated in an attempt to satisfy the SARS requirement. To connect the nozzle to the receptacle for operation, the nozzle is aligned with the receptacle and the engagement handles moved forward. As the handles move forward, the nozzle attaches to the receptacle and the ball shutoff valves in the fuel and vapor lines open. To disconnect, this process is reversed.

The nozzle and receptacle as delivered to the Government did not satisfy all of the SARS Purchase Description requirements. Specifically:

- Weight - The prototype is fabricated from stainless steel, causing nozzle and receptacle weight to exceed the 12 pound limit. The dry nozzle weighs 26 pounds. Moog estimates that the weight can be reduced significantly by using a lighter weight material and by incorporating production manufacturing methods. However, it is questionable if the weight can be reduced to the required 12 pound limit.

- Emergency disconnect - No consideration is given to this requirement. Moog states that this feature is extremely difficult to incorporate into its design.

- Shut off indicator - No means of determining when flow starts or stops is provided on the nozzle.

- Dust caps and fuel strainer - Neither an inlet fuel strainer nor dust caps were provided with the nozzle.

- Low flow operation - The ability of the nozzle to shutoff at low flow rates is questionable. Adequate differential pressure must exist for the nozzle to operate properly.

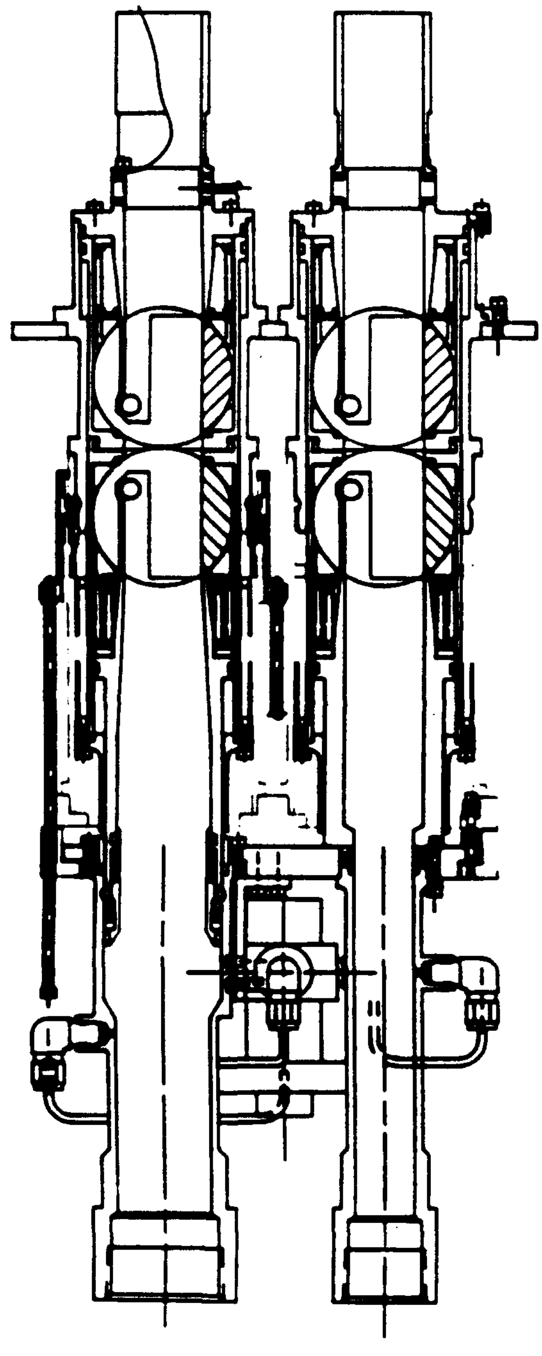

Figure 5. Cross Section of Moog Nozzle and Receptacle

Pretest Inspection

Prior to testing, we examined the nozzle and receptacle for missing or damaged parts, defects, and damaged seals. All parts appeared to be in working order. As shown in Figure 6, all control mechanisms and piping, required for the nozzle to function, are external to the basic structure of the nozzle and open to damage. It would require considerable design modification to shroud these items. The additional material needed to protect the sensing mechanisms and piping would add to the existing weight problem.

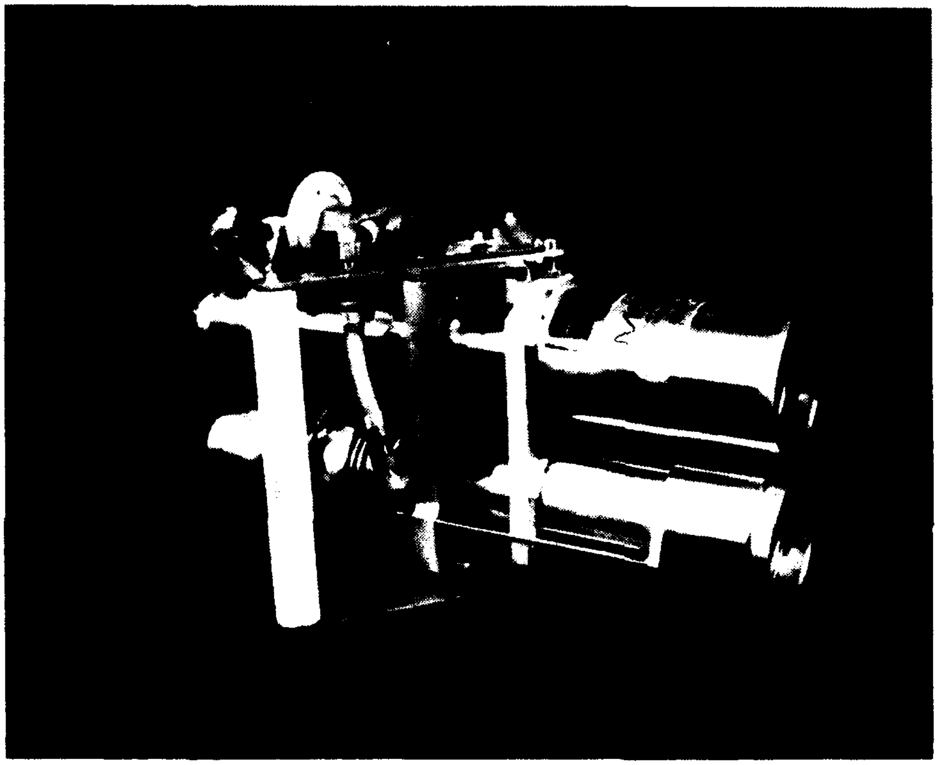

Figure 6. Picture of Moog Nozzle Showing the Exposed Hoses and Control Devices

Before starting the ON/OFF cycle test, we conducted flow tests to check the test stand for leaks and to verify nozzle performance. During these tests, the nozzle failed to terminate flow when the tank was full or when tank pressure exceeded 1.5 psig. An inspection of the nozzle and receptacle showed no reason for the malfunctions. The receptacle contains a small float valve that closes as the fluid level in the tank rises. Ideally, when the valve closes, it signals the nozzle to shut off. During the pretest, the fluid level in the fuel cell completely covered the float and rose to the bottom of the vapor return outlet before we turned it off manually. Table 7 provides a sample of the flow and pressure data recorded during one of the pretest runs. The nozzle never affected flow or pressure. Following four attempts at automatic shutoff, we aborted testing.

Table 7. Sample Flow and Pressure Data Recorded During Pretest Check-Out of Moog Nozzle

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
415	-0.1406	-0.0966	5.625	43.0117	66.3459	73.7182
416	-0.1406	-0.0825	5.4688	42.8594	66.316	73.6936
417	-0.1547	-0.1059	5.9375	44.1797	66.3547	73.7516
418	-0.1406	-0.0731	6.0938	45.1445	66.3775	73.8096
419	-0.1406	-0.0919	6.5625	45.043	66.309	73.6971
420	-0.1406	-0.0966	6.0938	45.2969	66.4549	73.7357
421	-0.1453	-0.1013	5.9375	45.3984	66.3617	73.8184
422	-0.1406	-0.0778	5.3125	45.5	66.3283	73.8342
423	-0.1266	-0.0731	6.0938	45.3984	66.3072	73.8729
424	-0.1359	-0.0919	5.9375	45.5	66.4109	73.7656
425	-0.1406	-0.1013	6.4062	45.5508	66.3775	73.8887
426	-0.1406	-0.0778	5.625	46.0078	66.4092	73.8605
427	-0.1313	-0.0731	5.9375	45.8555	66.5322	73.8605
428	-0.1313	-0.0825	6.5625	45.1953	66.3986	73.915
429	-0.1359	-0.0919	6.25	44.5352	66.4145	73.8834
430	-0.1172	-0.0872	5.9375	44.5352	66.3934	73.9045
431	-0.1313	-0.0966	5.3125	45.1953	66.4531	73.8201
432	-0.1406	-0.0919	5.9375	45.2969	66.418	73.8219
433	-0.1313	-0.0872	6.25	45.5508	66.4566	73.8412
434	-0.1313	-0.0872	5.7812	45.957	66.4232	73.8975
435	-0.1453	-0.0872	6.4062	46.7188	66.3951	74.0293
436	-0.1453	-0.0872	5.9375	47.2773	66.4373	73.901
437	-0.1266	-0.1106	6.25	47.7344	66.4953	73.8852
438	-0.1406	-0.0731	6.5625	47.4805	66.5322	74.0609
439	-0.1594	-0.0872	6.5625	47.4805	66.4795	73.9256
440	-0.1406	-0.0825	6.0938	47.6836	66.5006	73.9783
441	-0.1172	-0.0966	6.4062	47.6836	66.5006	74.017
442	-0.1266	-0.0591	6.5625	47.8867	66.5691	73.973
443	-0.1266	-0.0919	3.5938	42.8594	66.5533	73.9801
444	-0.1406	-0.0825	0.4688	7.1602	66.5076	73.9713
445	-0.1453	-0.1013	-0.1562	0.6094	66.4689	74.0363

Human Factors Engineering Evaluation

We conducted a human factors engineering evaluation to ensure conformance to MIL-STD-1472. As stated, a shutoff indicator was not provided as required by MIL-STD-1472, paragraph 5.2.1. The operator had no way of knowing when the tank was full or if flow had stopped. Excessive force was required to connect the nozzle to the receptacle. The force was not measured but appeared to exceed the limits of MIL-STD-1472, paragraph 5.4.4.2. The nozzle easily disconnected from the receptacle. The nozzle's large, well knurled handles provided for Arctic compatibility.

TUBE ALLOY NOZZLE AND RECEPTACLE

The Tube Alloy nozzle and receptacle operate together to control flow and pressure provided to the fuel cell. Figures 7 and 8 are assembly drawings of the nozzle and receptacle. The nozzle, attached to the receptacle with a dog latch mechanism, is installed by aligning it with the receptacle and pushing forward until the outer sleeve locks the holding dogs into place. To initiate flow, the handle is moved forward to the "OPEN FLOW" position. Once the tank is full, the indicator bulb pops out. The flow handle then is moved to the "NO FLOW" position. The nozzle is disconnected from the receptacle by pulling back on the outer sleeve.

Flow control requires the combination of regulated nozzle pressure and a properly sized receptacle orifice. Varying the orifice size allows flow to be tailored to any size fuel tank within the limits of the system. Tube Alloy provided three poppets for this testing. Table 8 gives flow characteristics for each poppet, as determined by the Tube Alloy test.

Table 8. Flow Rates for Tube Alloy Nozzle and Receptacle Test Orifices

	FLOW RATES (gpm) Nozzle Inlet Pressure (psi)				
ORIFICE NO.	25	50	75	100	125
1	83	75	71	72	71
2	154	146	153	156	168
3	229	233	236	246	266

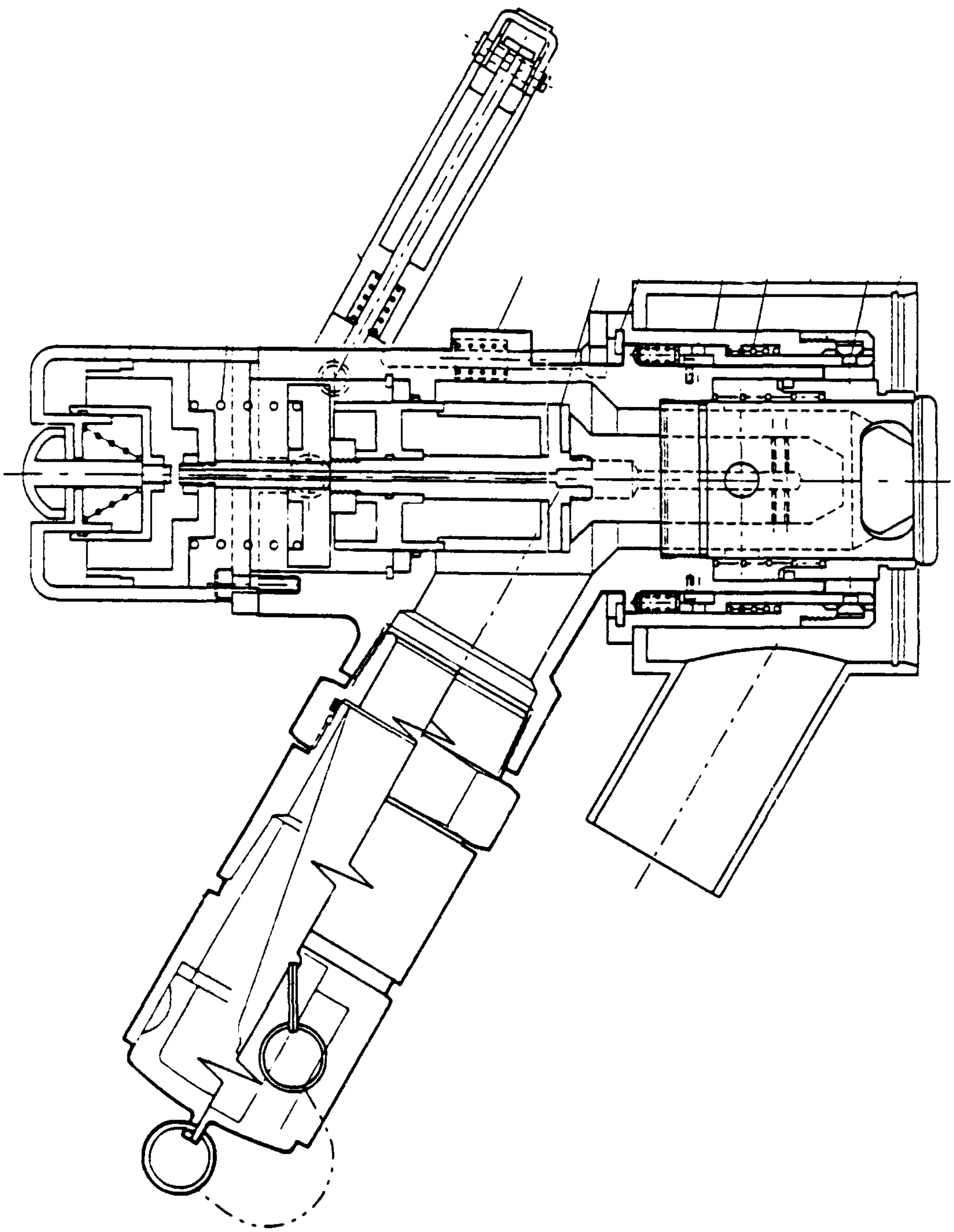

Figure 7. Cross Section of Tube Alloy Nozzle

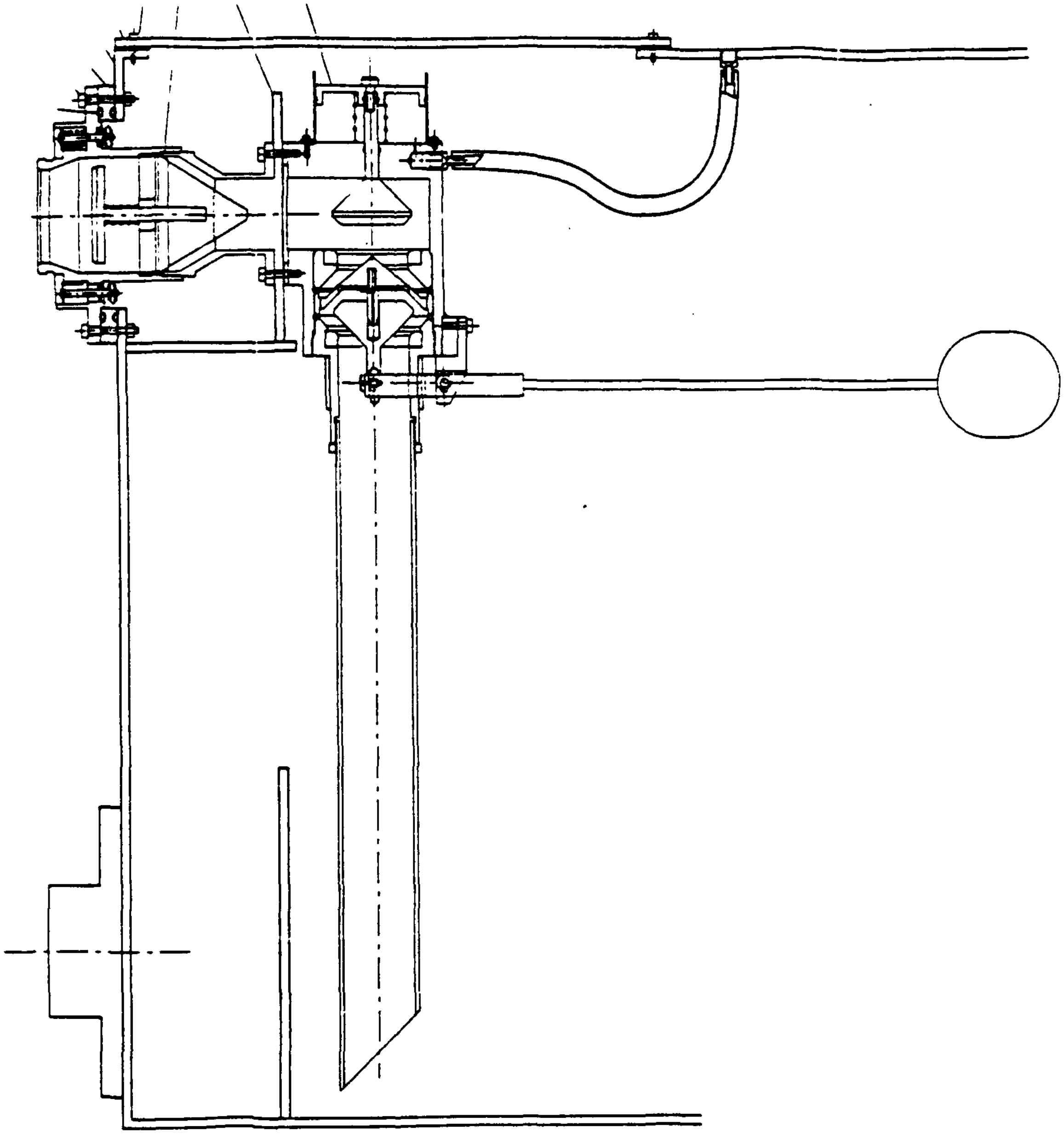

Figure 8. Cross Section of Tube Alloy Receptacle

The nozzle and receptacle as delivered to the Government did not satisfy all the requirements of the SARS Purchase Description. Specifically:

- Emergency disconnect - The nozzle is not provided with an emergency disconnect feature. The manufacturer proposed a design but did not test it. The breakaway is controlled by a split trapezoidal shaped ring. The prototype ring and outer sleeve are of the wrong materials to allow testing.

- Weight - 16 pounds.

Pretest Inspection

We examined the nozzle and receptacle for missing or damaged parts, defects, and damaged seals. All parts appeared to be in operating condition. The nozzle was equipped with a shutoff indicator, dust caps and both inlet and receptacle strainers. Its dry weight was 16 pounds.

Connect/Disconnect Test

With the receptacle mounted in the test tank, we performed 15 connect/disconnect cycles. The average time was 7.4 seconds, not including several failed attempts. To mate the nozzle to the receptacle, the operator was required to pull back an outer sleeve. This process was complicated by the absence of a handle on the outer sleeve. The vapor recovery line served as a handle, but this proved awkward. The manufacturer stated that the process simply required lining the nozzle with the receptacle and pushing forward but this procedure could not be duplicated during this test.

On/Off Cycle Test using Orifice Plate Number 1

We installed Orifice Plate Number 1 in the receptacle, activated the test loop and allowed 30 seconds of flow to pass through the nozzle. After 30 seconds, the nozzle handle was moved to the "NO FLOW" position. Table 9 gives a sample of the flow and pressure data recorded during this process. After several cycles, the nozzle failed to completely stop flow when the flow handle was moved to the "NO FLOW" position. Flow data provided in Table 10 shows that around 6 gpm continued to pass through the nozzle when the flow handle was in the "OFF" position. This malfunction continued throughout the remainder of the ON/OFF cycle testing. After 15 cycles, we closed the valve at the exit of the vapor return line, allowing internal tank pressure and vapor return line pressure to increase. As seen in Table 11, internal tank pressure reached a maximum of 2 psig before nozzle flow terminated. This pressure exceeds the 1.5 psig allowed by the SARS Purchase Description.

Table 9. Sample Flow and Pressure Data From On/Off Cycle Test of Tube Alloy Nozzle with Orifice Number 1 Installed

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
185	-0.1547	-0.0872	11.875	43.6211	76.673	74.7412
186	-0.1547	-0.0638	12.0312	43.7227	76.71	74.7693
187	-0.1641	-0.0872	12.0312	43.6211	76.6941	74.6955
188	-0.1359	-0.0919	12.0312	43.5195	76.7082	74.5355
189	-0.1547	-0.0778	12.0312	43.4687	76.7504	74.4424
190	-0.15	-0.0825	11.7188	43.6719	76.6748	74.3791
191	-0.1875	-0.0778	12.3438	43.4687	76.7592	74.3264
192	-0.1406	-0.0778	11.7188	43.5703	76.7715	74.184
193	-0.1594	-0.0778	12.3438	43.6211	76.6221	74.126
194	-0.1594	-0.0731	12.0312	43.6719	76.7205	74.1611
195	-0.1594	-0.0684	12.0312	43.6719	76.7398	74.017
196	-0.15	-0.0966	11.875	43.5703	76.7557	74.0293
197	-0.1453	-0.0825	11.875	43.6719	76.724	73.966
198	-0.1547	-0.0872	12.0312	43.7734	76.7539	73.8992
199	-0.1453	-0.0825	11.5625	43.9258	76.833	73.901
200	-0.1594	-0.0825	12.1875	43.7227	76.8277	73.843
201	-0.15	-0.0638	11.5625	43.7734	76.7416	73.9396
202	-0.1594	-0.0872	12.1875	43.9766	76.775	73.8395
203	-0.1453	-0.0778	11.7188	43.7734	76.7855	73.7199
204	-0.1547	-0.0919	12.1875	43.6719	76.8313	73.683
205	-0.1453	-0.0684	11.4062	43.6719	76.8049	73.567
206	-0.1688	-0.0825	12.0312	43.7227	76.8365	73.6074
207	-0.1734	-0.0919	29.2188	10.4609	76.8541	73.5424
208	-0.1547	-0.0919	26.7188	0.9141	76.8664	73.4211
209	-0.1641	-0.0778	27.0312	0.3555	76.8682	73.4229
210	-0.1547	-0.0731	26.25	0.3047	76.8682	73.4492
211	-0.1688	-0.0731	26.5625	0.3047	76.8383	73.4475
212	-0.15	-0.0919	26.0938	0.1523	76.8172	73.4176
213	-0.1734	-0.0825	25.9375	0	76.8523	73.3543

Table 10. Flow and Pressure Data Recorded During Operation of Tube Alloy Nozzle Showing Fluid Flow When Nozzle Handle is in the "OFF" Position

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
270	-0.0234	-0.0919	28.4375	40.9297	78.6312	78.5047
271	-0.0188	-0.0825	28.75	40.8281	78.684	78.3693
272	-0.0094	-0.0403	28.2812	40.8789	78.6945	78.35
273	-0.0188	-0.0825	28.5938	41.0313	78.6945	78.3043
274	-0.0328	-0.0684	28.4375	40.9805	78.7332	78.2305
275	-0.0281	-0.0966	28.4375	42.6563	78.5943	78.2639
276	-0.0281	-0.0872	27.9688	42.7578	78.5469	78.1865
277	-0.0281	-0.1013	28.5938	41.2852	78.466	78.0248
278	-0.0281	-0.0684	28.2812	40.4219	78.3869	78.1355
279	-0.0188	-0.0591	28.4375	40.1172	78.4361	78.0635
280	-0.0141	-0.0591	28.75	40.2695	78.4326	78.0318
281	-0.0281	-0.0966	28.5938	39.9648	78.4063	77.9668
282	-0.0422	-0.0403	30.4688	9.6992	78.4537	78.0178
283	-0.0469	-0.0403	30.7812	6.1445	78.4186	77.9738
284	-0.0422	-0.0544	29.6875	5.9922	78.3816	77.9879
285	-0.0656	-0.0497	30	5.9414	78.3307	77.9545
286	-0.0609	-0.0544	29.8438	5.9414	78.4432	77.951
287	-0.0703	-0.1106	29.375	5.5859	78.4221	77.9246
288	-0.0844	-0.0731	29.8438	5.7891	78.401	77.9721
289	-0.0656	-0.0544	30.1562	5.6875	78.3746	78.0037
290	-0.0797	-0.0825	30	5.7891	78.4713	77.9738
291	-0.0844	-0.0638	30.4688	6.0938	78.408	77.9422
292	-0.075	-0.1106	29.375	5.4844	78.3166	77.9229
293	-0.0844	-0.0731	30	5.7891	78.2375	77.9457
294	-0.0797	-0.0591	29.6875	5.7891	78.2604	77.9932
295	-0.0891	-0.0638	30.3125	5.7891	78.3131	78.023
296	-0.0797	-0.0731	30	5.8398	78.3377	77.9773
297	-0.0797	-0.0309	30.3125	5.8398	78.3553	77.9984
298	-0.0984	-0.0638	30.3125	5.8906	78.3553	77.9475
299	-0.0656	-0.0778	29.8438	5.6367	78.3939	77.8824
300	-0.0797	-0.1013	30.3125	5.6367	78.4273	77.9439

Table 11. Pressure and Flow Data Recorded During Automatic Shutoff of Tube Alloy Nozzle Using Orifice Number 1

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
458	1.7672	1.7784	25.1562	36.6641	78.6365	77.7734
459	1.7766	1.7738	25	36.3086	78.6523	77.682
460	1.7813	1.68	25.1562	36.6641	78.7367	77.733
461	1.8	1.8863	25.3125	36.3594	78.7209	77.733
462	1.8281	1.7175	25.3125	36.6641	78.6611	77.6873
463	1.8234	1.7738	25.1562	36.6133	78.7121	77.7348
464	1.8375	1.905	25.1562	36.6133	78.735	77.6908
465	1.8375	1.6706	24.8438	36.6133	78.7736	77.7471
466	1.8656	1.8769	25	36.5117	78.8211	77.7541
467	1.875	1.9097	25.1562	36.4102	78.8545	77.6873
468	1.8703	1.7784	24.6875	36.2578	78.8176	77.682
469	1.8891	1.9378	25.3125	36.5117	78.6717	77.7084
470	1.8797	1.8253	24.8438	26.8633	78.7297	77.6539
471	1.9125	1.8206	25.625	34.4297	78.7139	77.6662
472	1.8938	2.0269	25.3125	36.0547	78.7789	77.6504
473	1.9313	1.7503	25	36.1563	78.7332	77.6926
474	1.9313	1.9284	25.1562	36.207	78.6717	77.6539
475	1.9359	1.9894	25.1562	36.3086	78.6365	77.675
476	1.9406	1.7738	27.9688	25.8477	78.7156	77.624
477	1.9313	1.9894	26.25	15.3867	78.7367	77.6609
478	1.9266	1.8675	25.3125	14.625	78.8	77.6574
479	1.9359	1.83	25.3125	39.457	78.7754	77.6574
480	1.9359	1.8816	24.6875	35.6992	78.8018	77.6275
481	1.9266	2.0503	25	35.3437	78.8545	77.675
482	1.9641	1.7878	24.8438	35.3437	78.8211	77.682
483	1.9641	1.9988	25	35.293	78.8211	77.6768
484	1.9828	2.0222	24.6875	35.293	78.8211	77.6627
485	1.9734	1.8628	25.1562	35.1914	78.7807	77.6943
486	2.0016	2.0316	36.5625	35.0898	78.8756	77.7471
487	1.9781	2.0409	34.6875	4.8242	78.8756	77.7576
488	1.9781	1.83	32.3438	0.457	78.8879	77.7066

Next, we removed the receptacle from the test fixture and installed Orifice Number 2. During removal of Orifice 1, we found small pieces of a black rubber material on the strainer in the receptacle. The source of the rubber was unknown, but it was believed to come from an internal nozzle seal. The nozzle inlet was equipped with a strainer, therefore increasing the likelihood that the rubber originated from the interior of the nozzle. We resumed testing and the nozzle leaked severely at the receptacle interface allowing fuel to enter the vapor recovery line. The fuel settled/collected at a low point in the vapor recovery line and closed off the vapor path resulting in a combination of fuel and vapor escaping from the nozzle at the receptacle interface. We manually terminated flow and cleared the vapor line of fuel. Fuel flow was restarted with the same results. A visual examination of the face of nozzle and receptacle failed to reveal any reason for the leakage. The rubber pieces found on the strainer, in earlier testing, could be related to the problem. This malfunction resulted in termination of further testing.

Human Factors Engineering Evaluation

We evaluated the Tube Alloy prototype SARS nozzle for conformance to MIL-STD-1472. The mushroom shaped flow indicator provides a clear indication of flow/no flow conditions, thus satisfying the requirements of MIL-STD-1472, paragraph 5.2.1. The nozzle is very difficult to connect, requiring two hands to hold in position, and leaving no available hand to push the outer sleeve forward. The difficulty level in completing this connection will increase as the position of the receptacle is changed to shoulder height. With the receptacle location in the test stand at waist level, the lower body and legs can be used to assist in the connection. The flow handle is appropriately sized for Arctic mittens; however, the operator must actuate a thumb operated switch to unlock the handle. The thumb switch requires more dexterity than possible when wearing Arctic mittens.

IMO INDUSTRIES, WIGGINS CONNECTORS DIVISION, NOZZLE AND RECEPTACLE

Wiggins' design consists of three separate components working together to control flow and pressure. A nozzle, receptacle, and vapor vent valve operate in conjunction to limit internal tank pressure to less than 1.5 psig while filling the tank in less than two minutes. A cross section of each of the three components is given in Figures 9, 10, and 11. The nozzle connects to the receptacle using a dog latch mechanism. By pulling back on the flow handle, an outer sleeve is "cocked" in the ready position. The nozzle mates with the receptacle through a stabbing motion. When the nozzle achieves the proper position, the outer sleeve automatically releases, locking the nozzle to the receptacle. Removal is achieved by pulling back on the flow handle. This returns the outer sleeve to the "cocked" position and releases the clamping dogs. The nozzle primarily controls flow and pressure. Dynamic pressure, sensed at the outlet of the receptacle, is communicated to the nozzle through a small tube. The nozzle adjusts the flow or pressure provided to the receptacle accordingly. The fuel vapor returns from each fuel cell through vapor vent valves mounted in the top of each fuel cell. After exiting the vent valve, vapor is routed through the receptacle and nozzle back to the fuel source. As the fuel level rises in the cell, the vapor vent valve closes. This allows internal tank pressure to increase, signaling the nozzle that the cell is full. The nozzle closes and flow is terminated before tank pressure exceeds 1.5 psig.

Wiggins' nozzle/receptacle design satisfies all the requirements of the SARS Purchase Description, except:

- Defuel - The pressure regulating device chosen for the nozzle does not operate in the reverse direction.

- Dust caps - Neither the nozzle nor receptacle has a dust cap.

- Emergency disconnect - No emergency disconnect is provided. The manufacturer says that a frangible section can be installed on the inlet side of the nozzle to provide breakaway, but this does not satisfy the requirements of the SARS Purchase Description.

- Weight - The dry nozzle weighs 12.4 pounds, which is above the 12 pound limit.

Pretest Inspection

Prior to testing, we examined the nozzle, receptacle and vent valves for missing or damaged parts, defects and damaged seals. The adhesive on one vent valve flat seal started to fail, allowing the seal material to buckle. We removed the seal, cleaned the surface and reglued the seal. We noted no other defects. There was an indicator button on the rear of the nozzle and a strainer in the inlet. All moving parts were operational. We noted a problem with the flow handle stop pin. Under certain conditions, the pin was not adequate to withstand the level of force required to disconnect the nozzle. When the handle was pulled to disengage the nozzle from the receptacle, the stop pin bent and allowed the handle to move past the stop position. When disconnecting the nozzle, care had to be taken not to bend the stop pins. The dry nozzle weighed 12.4 pounds, which was above the 12 pound limit.

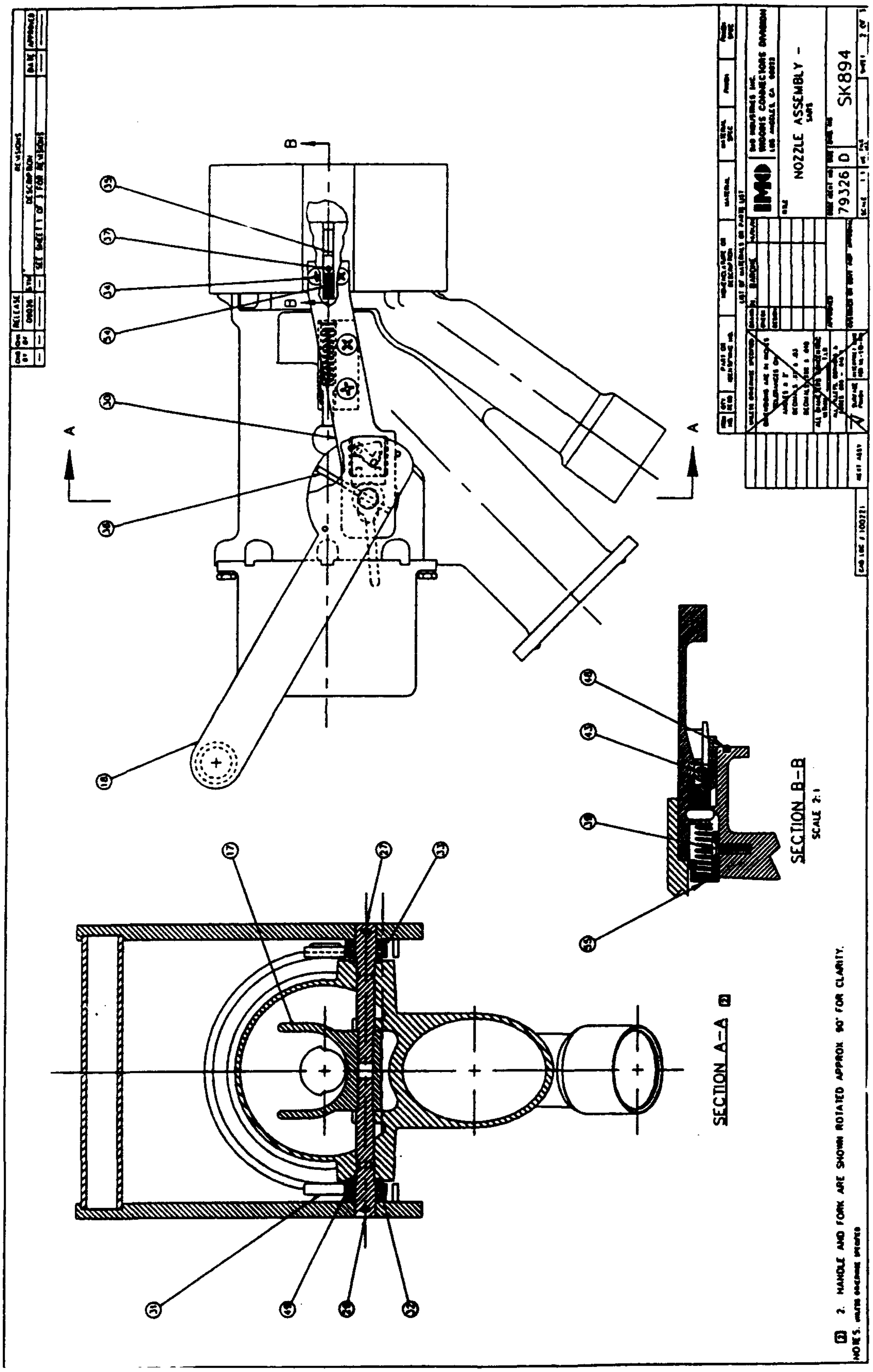

Figure 9. Cross Section of Wiggins' Nozzle

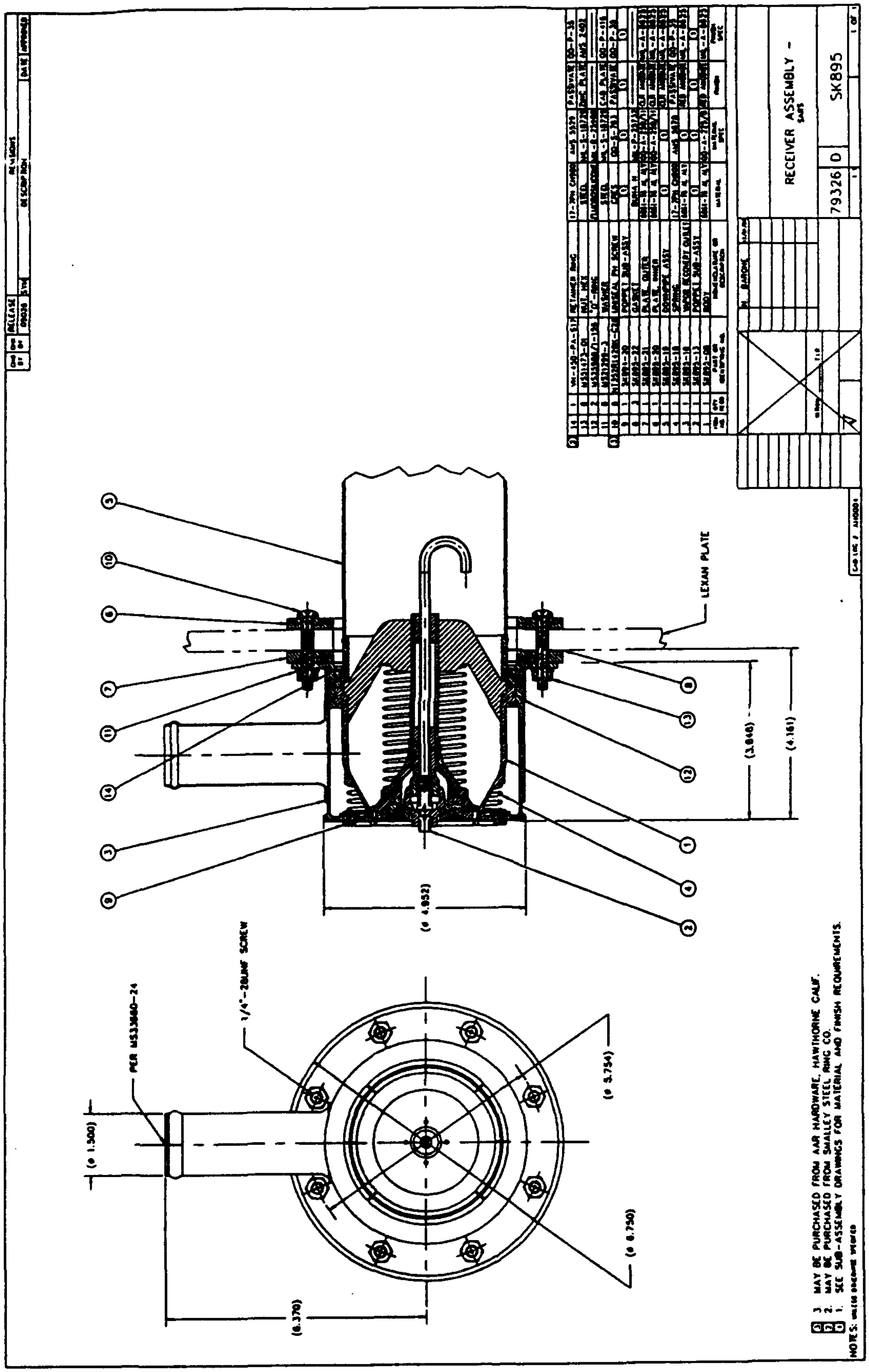

Figure 10. Cross Section of Wiggins' Receptacle

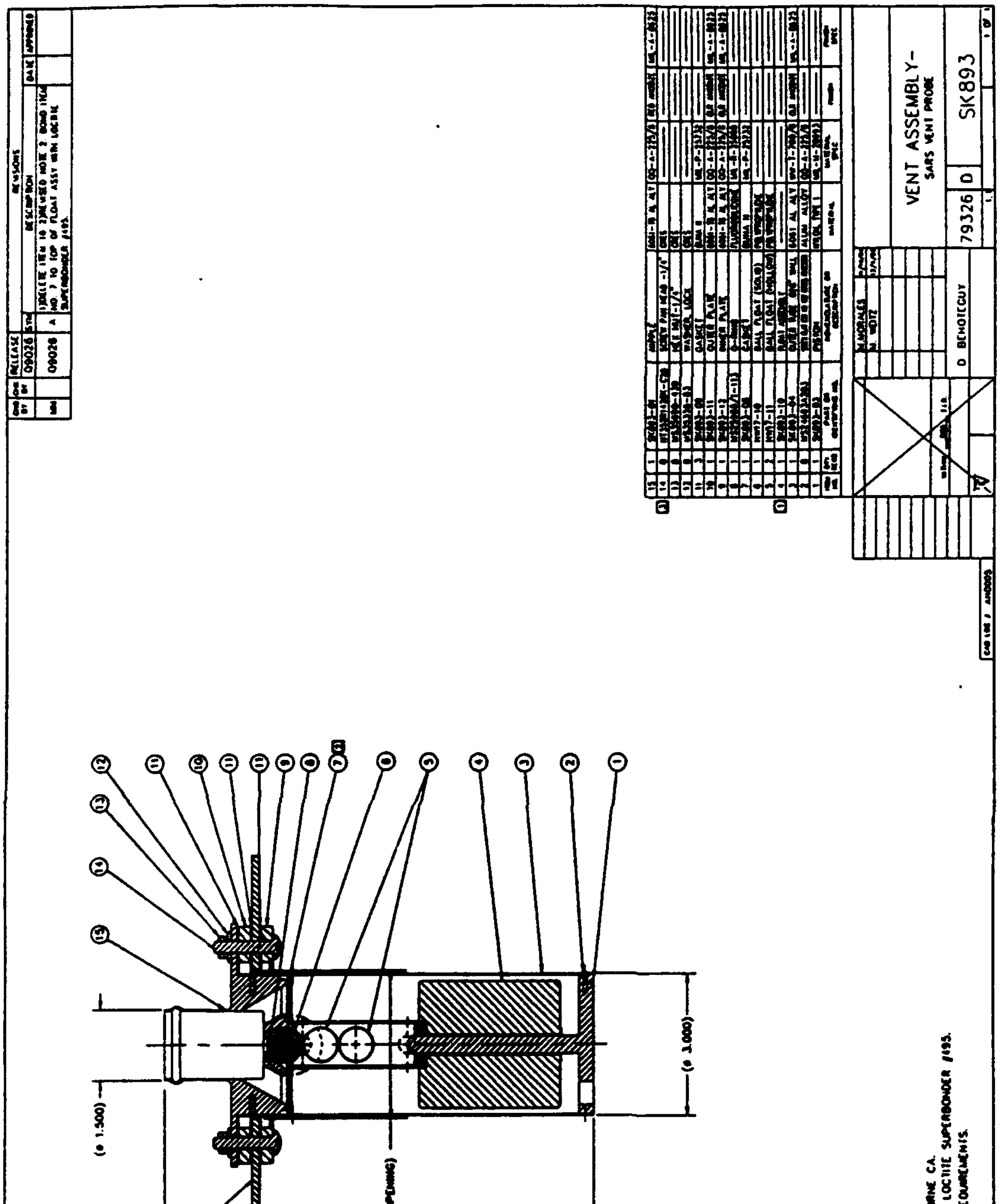

Figure 11. Cross Section of Wiggins' Vent Valve

Connect/Disconnect Test Nozzle 001

Prior to starting the connect/disconnect test, the operator completed several practice connections to become familiar with the required process. Connection of the nozzle became increasingly difficult after two cycles of the 15 cycle test. The outer sleeve of the nozzle would not reset properly, making a connection to the receptacle impossible to complete. To achieve connection, the outer sleeve was reset manually by pushing down on the end. The average connection time, once the sleeve was properly positioned, was 6 seconds. This average does not include several failed attempts before the outer sleeve was properly positioned. Releasing the nozzle from the receptacle worked as designed, except for the previously noted stop pin bending and an occasional binding of the outer sleeve.

On/Off Flow Cycle Test Nozzle 001

We installed the receptacle, vent valves, and nozzle 001 into the test loop and allowed flow to pass through the system. After 30 seconds, flow terminated when the flow handle was manually moved into the "OFF" position. After a few seconds, the handle moved forward and flow restarted without operator assistance. We returned the flow handle to the "OFF" position. Again after a few seconds, the handle moved forward and flow restarted without operator assistance. The flow data of Table 12 indicates that the nozzle remained closed approximately 4 seconds before reopening and allowing fuel to flow into the tank. We contacted the manufacturer who said the behavior was normal. The nozzle detected that the tank was not full, so it reopened the poppet to continue filling the tank. To solve this, we held the flow handle in the "OFF" position during the no flow portion of each cycle to override the automatic flow initiation feature. During the ON/OFF cycle test, the fuel tanks filled, requiring the nozzle to automatically terminate flow. Data recorded during shutoff, Table 13, indicates that internal tank pressure exceeded 2.8 psig before flow shutoff.

Table 12. Data Showing Ability of Wiggins Nozzle 001 to Return to Flow Condition Automatically

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
19	0.3141	-0.0591	7.6562	33.5938	75.6975	75.9488
20	0.2953	-0.0403	11.7188	32.1875	75.7748	75.9383
21	0.2813	0.0253	12.6562	12.1875	75.7309	75.9717
22	0.2438	0.0347	20.625	6.7188	75.7801	75.977
23	0.1922	0.1612	27.0312	3.4375	75.7854	75.9453
24	0.1828	0.1097	20.7812	1.25	75.9084	75.9365
25	0.1781	0.1519	21.25	0.1563	75.7695	75.9453
26	0.1688	0.0441	19.5312	0.1563	75.8117	75.9576
27	0.1641	0.1097	14.6875	5.1563	75.6904	75.9523
28	0.1594	0.1331	16.4062	17.0313	75.7818	75.9207
29	0.1641	0.1331	18.4375	17.0313	75.7713	75.9682
30	0.1359	0.0206	17.5	9.6875	75.8187	75.9523
31	0.1734	0.0769	11.875	11.875	75.7572	76.0227
32	0.2063	0.1706	7.1875	30.3125	75.9172	75.984
33	0.2109	0.1097	6.0938	36.5625	75.8469	76.1088
34	0.225	0.0534	6.25	37.0313	75.8574	76.0561
35	0.2391	0.2316	5.7812	36.7188	75.8803	76.0982
36	0.2578	0.2222	5.9375	37.0313	75.8434	76.1527
40	0.2813	0.1378	5.1562	36.875	75.8381	76.165
41	0.3	0.2456	6.0938	36.5625	75.8592	76.1105
42	0.2953	0.1378	5.7812	36.875	75.9049	76.1492
43	0.2672	0.0909	5.625	37.0313	75.8557	76.1281
44	0.2484	0.2034	33.4375	30.9375	75.8346	76.0824
45	0.225	0.2644	22.9688	6.875	75.9752	76.1299
46	0.1875	0.2644	21.4062	1.4063	75.9594	76.0666
47	0.1688	0.1941	18.75	0.3125	75.9242	76.0578
48	0.15	0.2222	21.5625	0.1563	76.0156	76.0789
49	0.1453	0.2128	18.75	0.625	76.0596	76.1176
50	0.1172	0.1144	16.25	15.9375	76.049	76.1826
51	0.1359	0.1753	15.1562	20.7813	76.1193	76.1352
52	0.15	0.2269	15.9375	21.5625	76.1738	76.1299

Table 13. Flow and Pressure Data Recorded During Automatic Shutoff of Wiggins Nozzle 001

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
221	-0.0656	-0.0825	7.8125	169.4336	77.8367	77.341
222	-0.0469	-0.0778	6.25	168.457	77.7225	77.3744
223	-0.0703	-0.0731	8.125	168.457	77.6609	77.2848
224	-0.0469	-0.0825	7.5	168.9454	77.7137	77.3639
225	-0.0656	-0.0544	7.5	167.4805	77.6416	77.3691
226	0.1125	-0.0544	8.2812	167.9688	77.6785	77.2883
227	0.4359	-0.0825	8.125	168.457	77.726	77.3568
228	0.8484	-0.0638	8.125	168.9454	77.7893	77.3604
229	1.2656	-0.0825	9.0625	169.4336	77.8121	77.4342
230	1.6781	-0.1013	8.9062	166.0156	77.849	77.3111
231	2.1234	-0.0919	9.375	164.5508	77.965	77.2742
232	2.5406	-0.0872	19.8438	159.668	77.9598	77.3287
233	2.7656	-0.0872	32.3438	100.5859	77.8912	77.2338
234	2.8078	-0.0778	44.0625	24.9023	77.9773	77.2988
235	2.8547	-0.0872	42.1875	1.9531	77.951	77.4078
236	2.8125	-0.0825	40.625	-0.4883	77.9826	77.4553

After several ON/OFF cycles, a mixture of fuel and vapor began leaking at the interface of the nozzle and the receptacle. The leak was steady and allowed fuel to enter the vapor return passageway. The leak was severe enough that testing of prototype nozzle 001 was discontinued.

Connect/Disconnect Test Nozzle 002

We installed Wiggins nozzle 002 in the test loop and restarted testing. During the connect/disconnect test, the nozzle would no longer connect to the receptacle. The dog locking mechanism would not reset. Manual reset of the dog allowed the nozzle to attach to the receptacle, but this coupling procedure deteriorated until completing the connection was impossible. We contacted the manufacturer to obtain possible solutions to the problems experienced. Wiggins supplied a special tool and made a simple adjustment to the poppet in the end of nozzle 001, which eliminated the interference leaking problem. We removed nozzle 002 from further testing.

Restart On/Off Flow Cycle Test Using Nozzle 001

With nozzle 1 reinstalled in the test fixture, a 30 second flow/no flow test was conducted. During this test, flow failed to start after the nozzle handle was moved to the "Flow" position. The nozzle was disconnected from the receptacle and then reconnected. We moved the flow handle forward and flow began. This flow failure pattern continued for several cycles. Each time the nozzle failed, it had to be disconnected and reconnected before flow would resume. After disconnect at 22 psig, a small stream of fuel was spraying out of the nozzle around the end poppet. The nozzle was connected to the receptacle and flow passed through it for 30 seconds. After the flow portion of the cycle, the nozzle was disconnected, but fuel stream continued and appeared to intensify. The flow/no flow cycles continued at increasing flow rates and inlet pressures. At approximately 60 psig inlet pressure, the operator was attempting to connect the nozzle to the receptacle when fuel started flowing out of the nozzle. The system was immediately shutdown. After shutdown, the main nozzle pin that controls the poppet was found laying on the ground. Exact cause of the failure could not be determined. Flow and pressure values recorded during the failure are provided in Table 14.

We terminated testing of the Wiggins prototype SARS nozzles due to the failure of both prototypes.

Table 14. Flow and Pressure Data Recorded During Failure of Wiggins Nozzle 001

TIME (seconds)	TANK PRESSURE (psig)	VAPOR PRESSURE (psig)	LINE PRESSURE (psig)	FLOW (gpm)	AMBIENT TEMPERATURE (°F)	FUEL TEMPERATURE (°F)
207	-0.1406	-0.0872	60.1562	-1.9531	80.9393	85.6836
208	-0.1219	-0.0638	59.5312	0.9766	80.8918	85.5465
209	-0.1313	-0.0638	59.0625	0.9766	80.7951	85.615
210	-0.1172	-0.0825	59.5312	0	80.9041	85.5799
211	-0.1266	-0.0638	58.75	1.9531	80.8725	85.6291
212	-0.1266	-0.0778	59.5312	3.9063	80.9393	85.5764
213	-0.1219	-0.0684	11.7188	1.9531	80.8408	85.673
214	-0.1125	-0.0684	6.0938	59.082	80.8707	86.1582
215	-0.1219	-0.0731	-2.6562	25.3906	80.9357	86.3832
216	-0.1313	-0.0403	-3.125	1.4648	80.9164	86.4904
217	-0.1453	-0.0731	-3.125	1.9531	80.948	86.3639

Human Factors Engineering Evaluation

We performed a human factors engineering evaluation to determine conformance of the Wiggins nozzle to MIL-STD-1472. The pop out indicator for flow/no flow does not provide a clear indication of flow as required by paragraph 5.2.1 of MIL-STD-1472. The nozzle is difficult to connect. As stated previously, the locking dogs do not fully retreat and must be reset manually. The nozzle handles are appropriately sized for Arctic mitten capability.

Section V
Summary

The premature failure of the prototypes limited the amount of operational testing performed. However, the information produced will be useful in directing future SARS development. Specific results and observations relating to all four SARS prototypes are provided below:

- None of the four prototype nozzles/receptacles satisfies the requirements of the SARS Purchase Description.
- None of the prototypes has the capability to automatically disconnect from the receptacle in an emergency. Each manufacturer states that this requirement is very difficult to accomplish without increasing nozzle weight, size, and complexity.
- All prototypes exceed the 12 pound nozzle weight limit. Each design incorporates most of the control devices into the nozzle, thus increasing the size, weight, and complexity of the nozzle.
- To satisfy the SARS Purchase Description, each prototype is designed to service multiple fuel cells from a single location. All systems tested rely on a passive crossover system to transfer fuel. This type of design requires large crossover pipes mounted in the bottom of the fuel cell. These pipes consume a considerable amount of limited space within a vehicle and add a significant amount of weight.
- The addition of a separate vapor return hose makes it extremely difficult to maneuver the nozzle into position for connection.
- All prototypes experience difficulty in limiting internal tank pressure to less than the required 1.5 psig. Under test conditions, tank pressures at flow termination are approximately 2 to 3 psig.

Section VI
Conclusion

Information gained during the design, manufacture, and test of the SARS prototypes suggests requirement changes are needed. These changes should include the allowance of a pressure manifold type refueling system, possible removal or redefinition of the emergency breakaway requirement, and establishment of a maximum required delivery pressure for maximum flow. These changes will allow a design that moves some of the control devices from the nozzle and receptacle to the individual fuel cells.

Appendix

Requirements for the Standard Army Refueling System (SARS) Nozzle and Receptacle

1. Purpose: Currently a deficiency exists to rapidly refuel combat vehicles. The Standard Army Refueling System (SARS) is an attempt to refuel each hydro-carbon powered vehicle or equipment within two (2) minutes through a single port. For example, if a truck has two fuel tanks with a total fuel capacity of 150 gallons, then it should be refueled at a rate of 75 gallons per minute (GPM) through a single port.

The SARS nozzle/receptacle will be incorporated in all equipment designed, procured, and used by the U.S. Army. The SARS nozzle will replace all fuel nozzles currently in the Army inventory.

2. Definitions: The following definitions apply:

a. Standard Army Refueling System. The Standard Army Refueling System consists of a refueling nozzle and equipment receptacle that has been designed based on ground support refueling equipment delivery capabilities and the equipment fuel system flow characteristics. Together, the nozzle and receptacle operate to allow fuel transfer through a single point at the acceptance rate of the equipment without external fuel contamination, spillage, vapor plume, and undue safety hazards.

b. Standard Refueling Nozzle. The standard refueling nozzle is a single point pressure nozzle that will deliver fuel through interlock with the standard refueling receptacle. The standard refueling nozzle will use an appropriate adapter for gravity refueling.

c. Standard Refueling Receptacle. The standard refueling receptacle will receive the standard refueling nozzle and will accept fuel up to the maximum flow rate specified for the equipment. The standard refueling receptacle will accept a gravity refueling adapter.

d. Ground Support Refueling Equipment. The ground support refueling equipment includes pump, hose, filter/separator, regulator, bonding, and ancillary equipment that has the capability of delivering fuel through the SARS up to the maximum acceptance rate of the receiving equipment.

e. Equipment Fuel System. The equipment fuel system includes fuel tanks, vents, and fuel tank interconnects that allow fill-up of all fuel tanks from a single fill point, or any one of multiple fill points, through a SARS at the maximum acceptance rate specified for that equipment.

f. Equipment. The term equipment in the context of the SARS refers to all hydro-carbon powered vehicles and equipment, including aircraft, having on-board fuel storage capability.

g. Vapor Recovery. The collection of escaping vapors from the equipment fuel system while the equipment fuel system is being refueled and the releasing of these vapors into the ground support refueling equipment.

3. Requirements: The requirements for the SARS nozzle/receptacle shall include but not be limited to:

a. One nozzle with variable flow rates from 0 to 300 GPM.

b. Provide for total vapor recovery from the equipment fuel system and return of these vapors back to the ground support refueling equipment. Vapor recovery line should be sized to minimize the buildup of static charge.

c. The nozzle shall be equipped with an automatic shutoff mechanism at full tank condition such that:

1) Surge pressure at shut-off shall not exceed 1.5 times the fuel delivery pressure.

2) The mechanism shall not cause premature fuel shutoff due to foaming.

3) It will be equipped with a mechanism to indicate that the nozzle has shut off.

d. Be capable of defueling at a minimum rate of 50% of maximum receptacle acceptance flow rate while still maintaining vapor recovery.

e. The nozzle shall be designed so that it can be connected to the receptacle by a 5th percentile female soldier defined in MIL-STD-1472 and MIL-HDBK-759.

f. The weight of the SARS nozzle shall not exceed 12 pounds.

g. The flow-control handle shall remain in either the flow or non-flow position, as selected by the operator under the full range of flows and pressures, without the need of maintaining continuous manual holding force.

h. Provide an airtight fit between the mating nozzle/receptacle such that it shall:

1) Be impossible to operate the flow-control handle from the non-flow to the flow position unless the nozzle is securely locked to the receptacle.

2) Be impossible to remove the nozzle from the receptacle unless the flow-control handle is in the non-flow position.

3) Be equipped with a dry break quick-connect/-disconnect feature between the nozzle and receptacle so that the receptacle will close allowing no contamination of the equipment fuel system or allow vapors to escape.

i. Provide an emergency disconnect feature such that if a vehicle being refueled leaves before the nozzle is disconnected there will be no damage to the SARS and no fuel spillage per MIL-STD-1472, para 5.13.7.3.2.

j. The nozzle/receptacle shall not cause the internal fuel tank pressure to exceed 1.5 psig.

k. The nozzle/receptacle shall not cause excessive fuel foaming.

l. The nozzle assembly shall be equipped with a ground cable assembly for grounding the nozzle to the vehicle and to a ground stake. The nozzle-to-vehicle ground cable shall conform to MS25384, except the clip shall conform to MIL-C-83413/7. The nozzle-to-ground stake cable shall be coated wire 15 feet long, and the end shall be equipped with a clamp in accordance with MIL-C-83413/7, suitable for bonding the cable assembly to a 5/8-inch diameter ground stake.

m. Complete electrical contact between the nozzle and adapters and nozzle and receptacle shall be established through the attaching mechanism when the units are connected. When the nozzle is coupled to the receptacle the electrical resistance between the receptacle and the plug on the ground cable shall not exceed 10 ohms.

n. The nozzle and receptacle should remain coupled with no outside support and with no damage to the system.

o. The SARS should be operational in temperatures of -60°F to +125°F. It should be sufficiently rugged for reliable operation by soldiers in a hostile environment.

p. Materials used in the SARS nozzle/receptacle should be nonsparking and compatible with fuels and fluids conforming to MIL-F-46162, MIL-G-5572, MIL-T-5064, MIL-T-83133, and W-F-800 without degradation.

q. The SARS nozzle/receptacle shall be protected from the environment so that no contaminants can enter when not in use.

r. The SARS nozzle assembly should provide a threaded female quick disconnect coupler per MIL-C-27487 for connection to a fuel supply hose.

s. The SARS nozzle/receptacle should be capable of withstanding a maximum inlet working pressure of 125 psi and a maximum burst pressure of 250 psi.

t. A removable strainer of approximately one-sixteenth inch mesh shall be installed within the nozzle to prevent the passage of foreign matter.

u. The nozzle/receptacle design shall reflect applicable system and personnel safety factors including minimizing potential human error in the operation and maintenance of the system particularly under the conditions of alert or battle stress. Design shall also minimize personnel and training requirements to operate and maintain the system. Design should conform to MIL-STD-1472, Human Engineering Design Criteria and Military Systems Equipment and Facilities, where applicable. Particular attention should be paid to the following:

1) All exposed corner and/or edges should be rounded to a minimum of .75mm (.03 in) radius to eliminate snagging/cutting or puncturing hazards. Actuation of levers/controls shall not expose personnel to pinching hazards.

2) Should the SARS nozzle require handles for lift/carry/connect or disconnect, handles shall conform to MIL-STD-1472, Paragraph 5.9.11.5 Handles and Grasp Areas. This would include storage and transportability requirements as well. Non slip handles are required.

3) The SARS nozzle shall be designed to enhance maintainability by trained personnel existing within the established MOS structure now present within the Army. Design for maintainability shall be in accordance with MIL-STD-1472, Paragraph 5.9 Design for Maintainability. No special tools shall be required for maintenance.

4) Labels, legends, placards, signs or markings, or a combination of these shall be provided whenever it is necessary for personnel to identify, interpret, follow procedures or avoid hazards. Labeling of any control valves, or other operating features of the SARS nozzle should adhere to the guidelines of MIL-STD-1472, Paragraph 5.5. If particular lettering characteristics cannot be achieved due to space constraints the sections regarding accuracy, positioning and high contrast for readability take priority.

5) Any controls, including dry break levers, valve open/close levers, etc. shall conform to requirements of MIL-STD-1472, Paragraph 5.4 Controls. Particular attention shall be paid to the necessity for personnel to operate the SARS nozzle while in cold/wet gear, arctic mittens and Mission Oriented Protective Posture (MOPP) Gear, Level IV.

6) The SARS system should not impose any additional safety hazards above the current military nozzles.

4. Non-Material Requirements

a. Participate in design review meeting at VSE to discuss design details prior to hardware fabrication.

b. Provide detailed interface information on nozzle and receptacle to allow test fixtures to be fabricated.

c. Provide information in manufacturers format to include operating instructions, maintenance instructions, design information and engineering drawings.

d. Provide verification of product compliance with all requirements listed. Verification will be in the form of test results, certificate of compliance, etc. VSE shall be given the option to witness all verification tests performed. Contractor shall provide seven (7) days advance notice of testing.

5. Desired Features: The following is a list of desired features for the SARS nozzle/receptacle that are expected to become requirements in future developmental efforts. These features should be considered in the design and incorporated wherever possible. All features that are not incorporated should be identified along with an explanation of how the feature would be incorporated into future designs if required, and the associated cost.

a. It is desired that the SARS system will automatically regulate fluid flow to the maximum acceptable flow rate of the equipment fuel system when the nozzle flow-control handle is in the flow position. For example the SARS system will automatically regulate flow for a 150 gallon capacity fuel system to 75 GPM or a 500 gallon capacity fuel system to 250 GPM without operator assistance when the nozzle flow-control handle is in the flow position.

b. The SARS nozzle/receptacle will be used on an armored refueler (To be developed at a later date) which will incorporate a robotic arm with the SARS nozzle attached to the end. This robotic arm will make the connection to the receptacle and then initiate flow. It is desired that SARS nozzle/receptacle be designed so that it can be used in this mode. The main form of operation will be manual.

c. Adaptability to the family of refueling systems currently in use by the U.S. Army to include the CCR, D-1, and the open port service station type nozzles. There shall be no physical modifications to vehicle chassis or receptacle orifice for nozzle adapter adaptation to existing military equipment. A SARS receptacle adapter to the receptacle of the equipment fuel system is desired so that current military equipment can be equipped to use the SARS nozzle.

d. It is desired that the SARS receptacle be able to accept current nozzles in the U.S. Army Inventory or be equipped with an adapter.

e. It is desired that the pressure drop across the nozzle and receptacle be less than 10 psi at all flow rates.

f. It is desired that the nozzle/receptacle design conforms to existing fuel nozzle requirements found in MIL-N-5877, MIL-N-52747, MIL-N-52748, and MIL-N-52110. These design requirements include but are not limited to:

1) Material
2) Environmental Operating Conditions and Storage
3) Maintainability
4) Reliability
5) Construction
6) Interchangeability
7) Lubrication
8) Workmanship

It is desired that the nozzle/receptacle pass all applicable Quality Assurance tests listed in MIL-N-52747 and the other military standards listed in this paragraph.

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